Building a Snow Model Capable of High Spatial Resolution Simulations into the Land Information System

Spatially Explicit Snow Simulations in LIS

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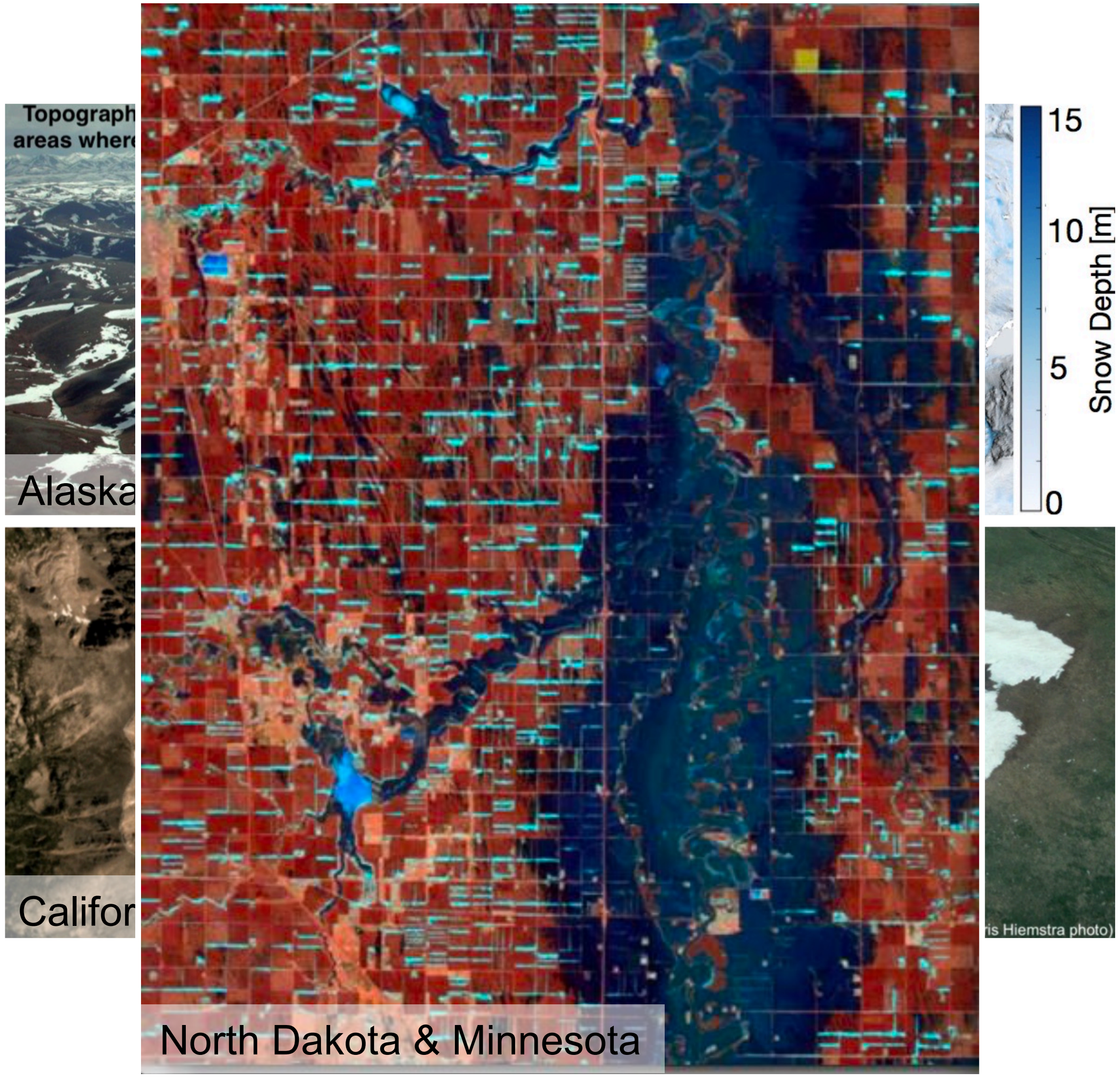
The need for high-resolution snow in LIS

Snow, the Earth System, and Society:

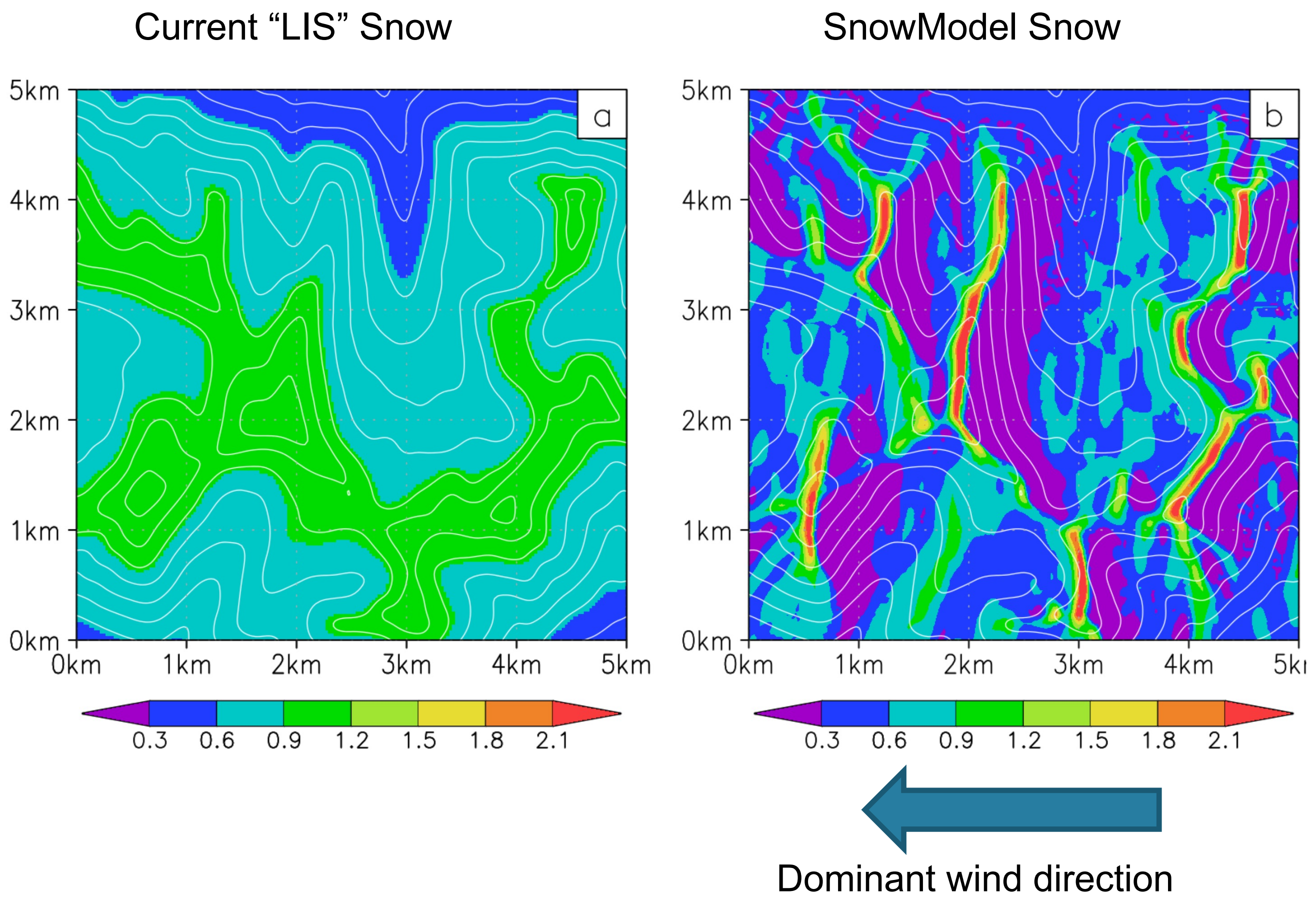
- Snow is a critical water resource; it is susceptible to climate change, and the albedo feedback will change climate and weather.
- LIS snow is used for mission planning and data assimilation.
- The representation of snow in LIS now is one dimensional
- Real snow is extremely heterogenous
- Variability comes from processes not represented in LIS



Adding SnowModel to LIS provides key processes

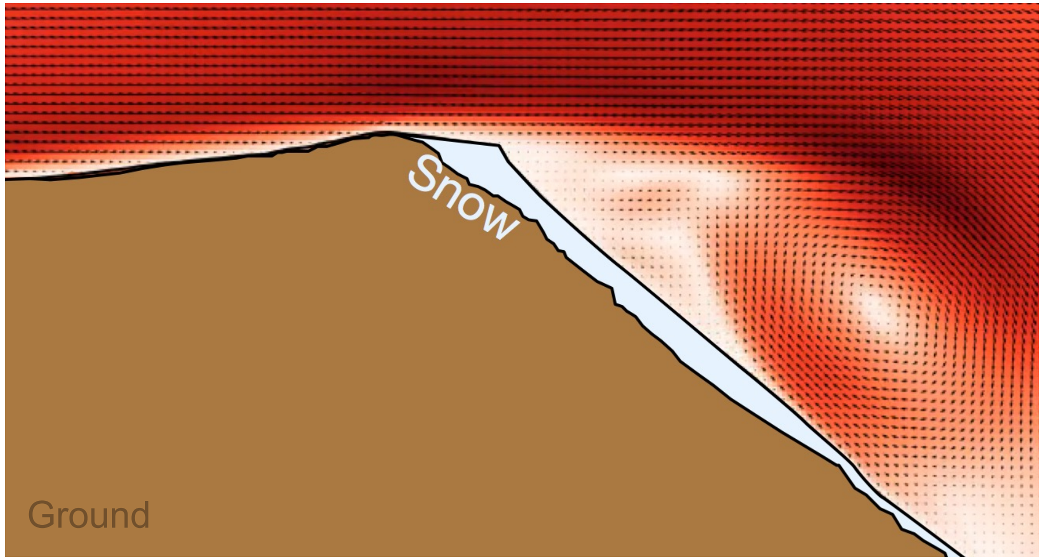
Key Processes

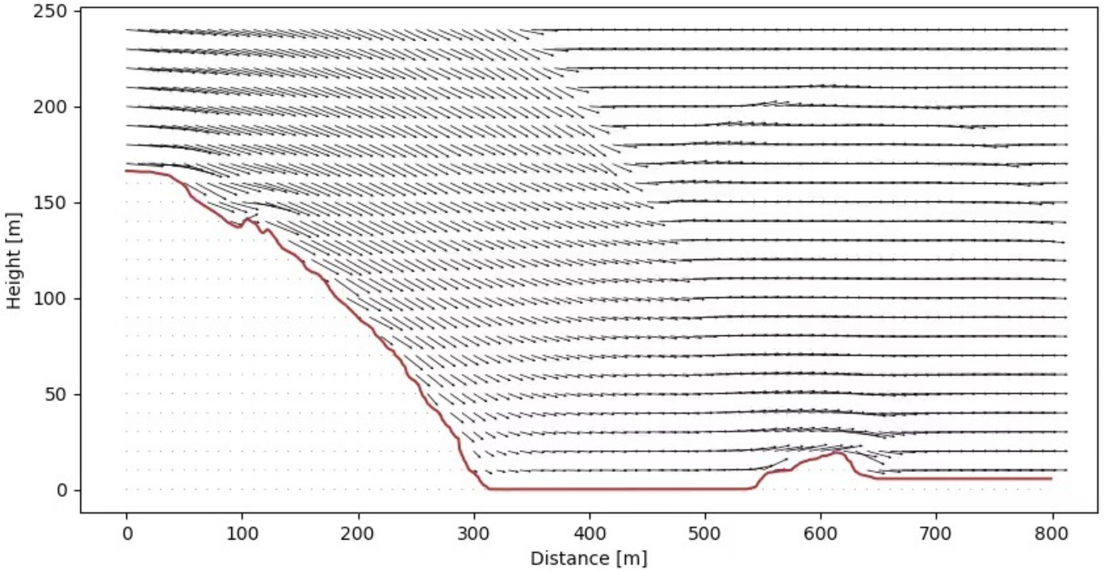
- Snow transport and deposition
- Snow surface cohesion
- High-resolution wind field over terrain
- Adjustments to solar radiation, temperature, and precipitation



Technical Details

- Addition of MicroMet meteorology
- Coupling of SnowModel in LIS
  - Parallelization of SnowModel
  - Adding ability to communicate across processes in a LIS model
  - Connection between SnowModel and Noah-MP land model
  - Ability to use distributed memory to permit CONUS scale O(100m) grid simulations.
- Optimization and tuning, possibly parallel file IO in LIS
- Testing in continental domain OSSE to show impacts



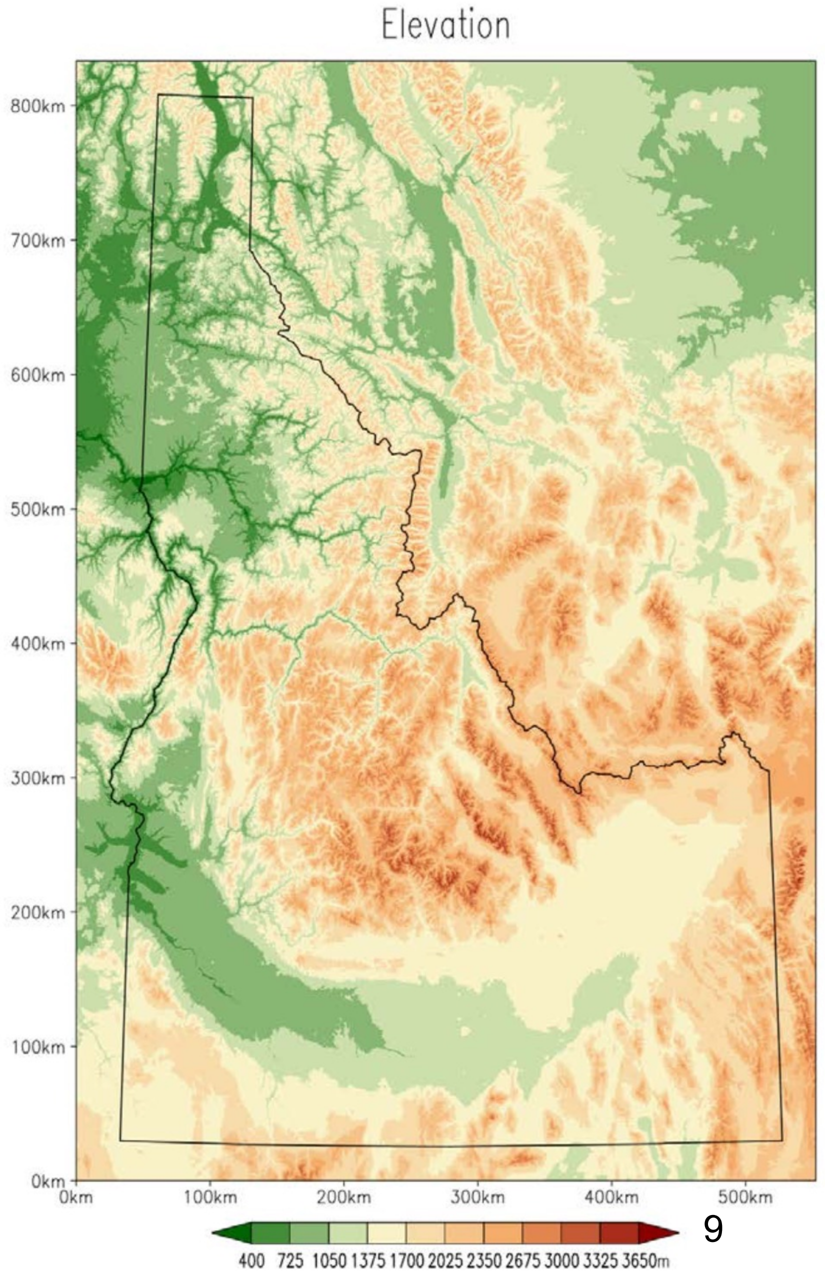


Importance of Computational Scaling

- SnowModel simulations are serial
- Before this project, largest domain:
  - 6,140 x 9,258 (90 m) grid cells
  - 24yr simulation
  - CPU: 269 days + 8:39:42

CONUS domain will be ~50x larger

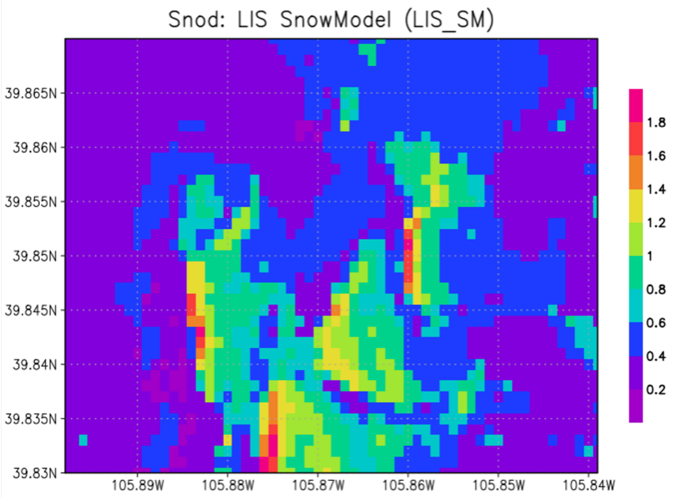
Goal: parallelize ~100-1000x efficiently

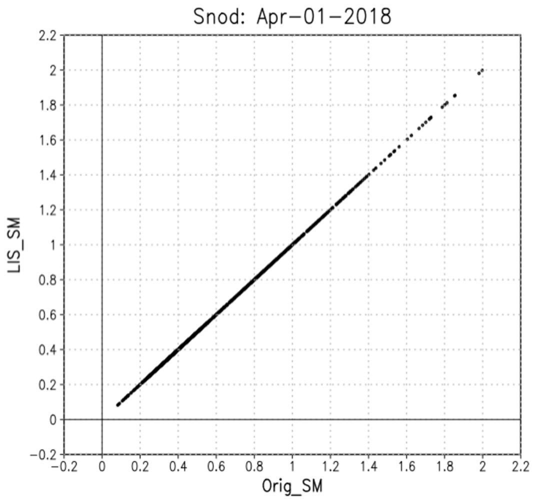


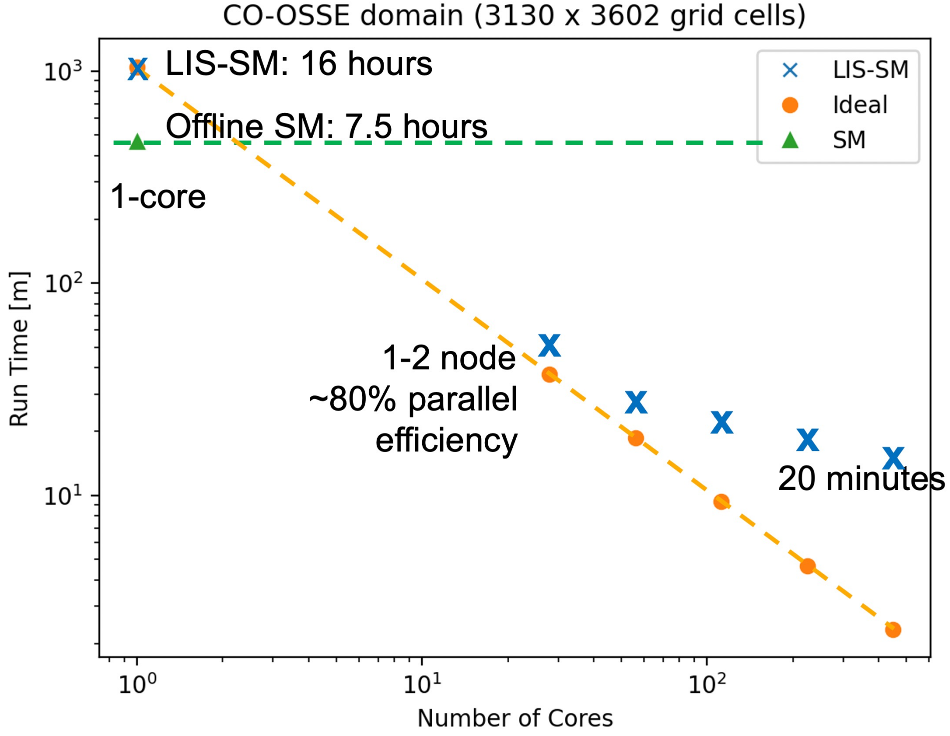
Initial Implementation

SnowModel runs in LIS!

- LIS-SnowModel and offline SnowModel results are identical
- Initially MicroMet coupled within SnowModel (in LIS)
  - Most routines now available in LIS forcing engine
- Initial parallelization efficiency scaled poorly





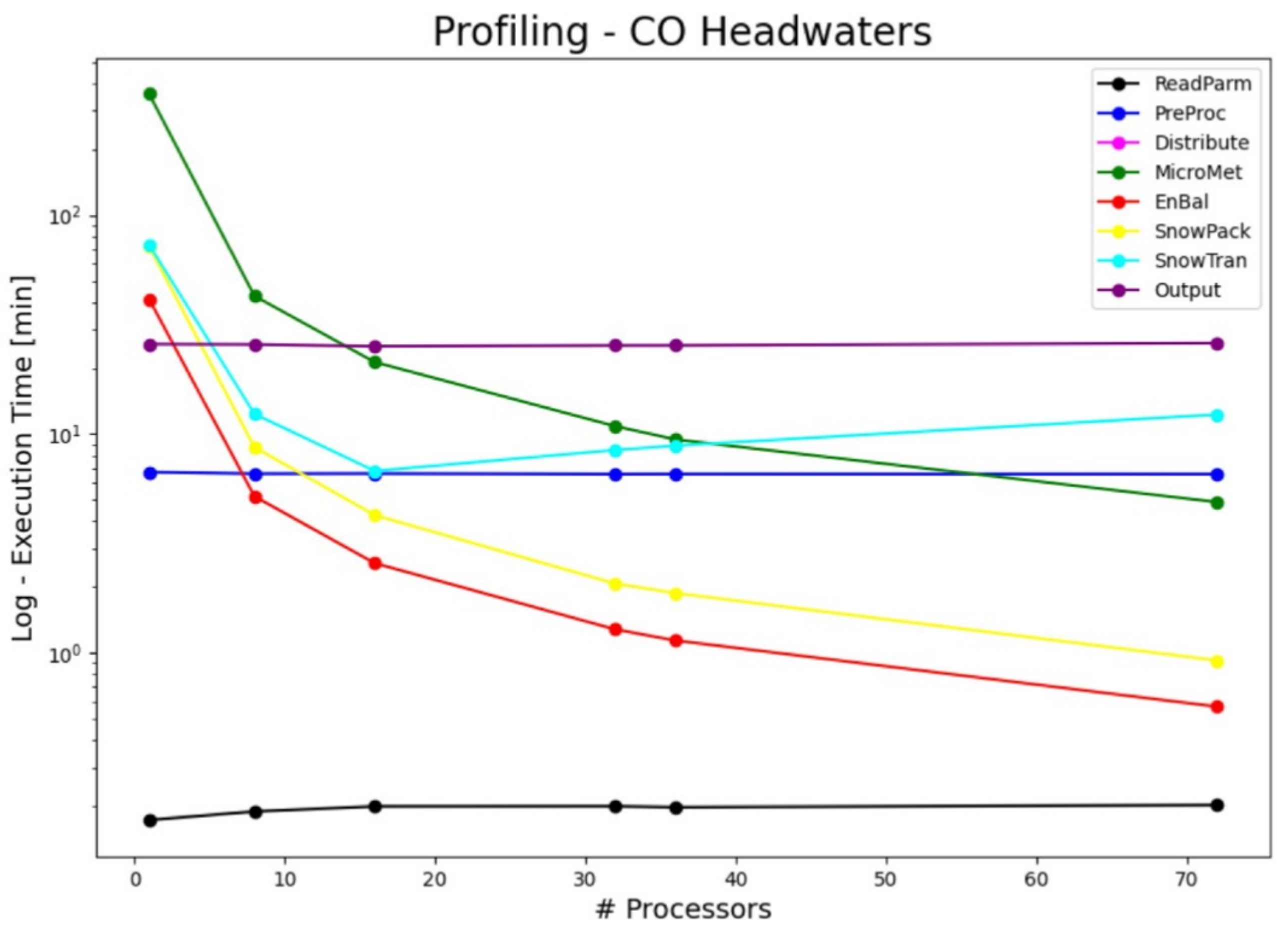


Computational Scaling Improvements

Identifying and mitigating hotspots in the code

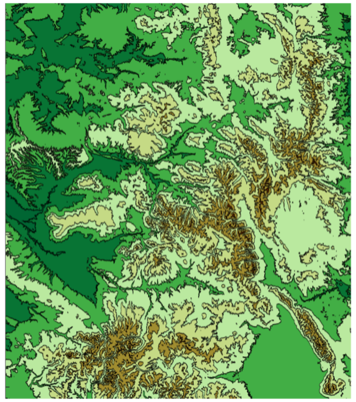
- File IO parallelized (outside LIS)
  - Testing asynchronous IO in LIS
- Snow Transport synchronizations minimized
- Global domain array allocations eliminated

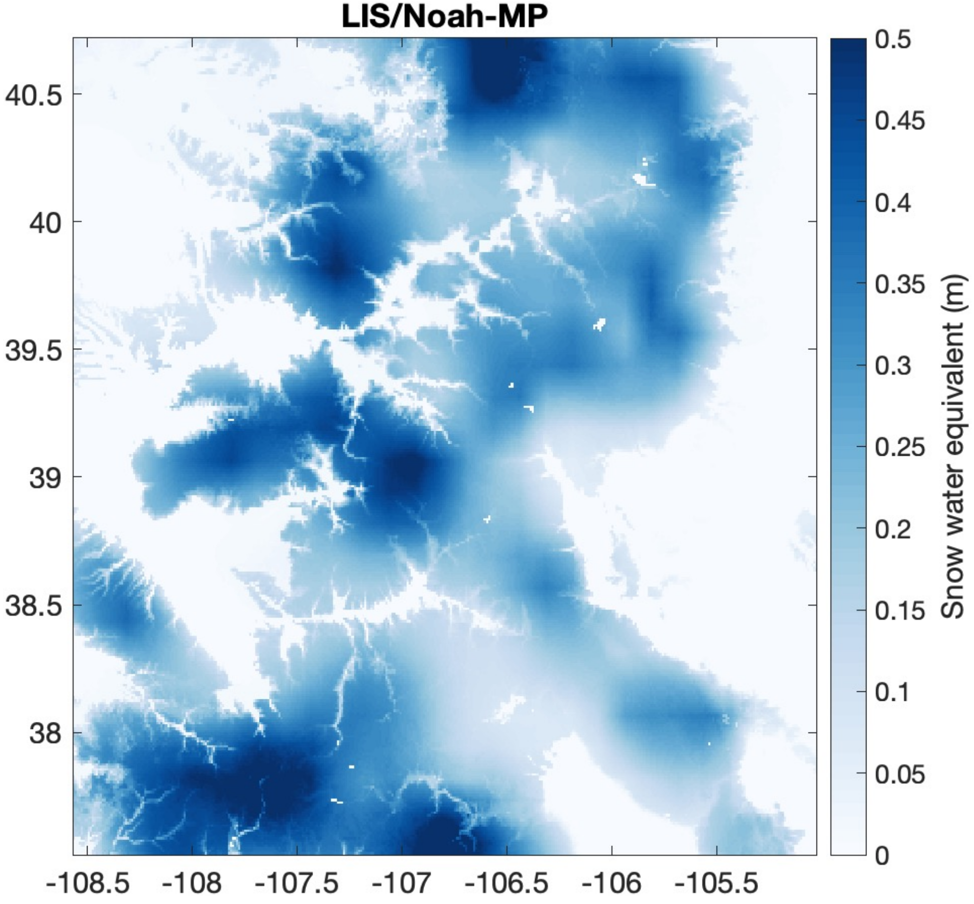
- Previous simulation requiring 269 days can now be completed in < 24 hours

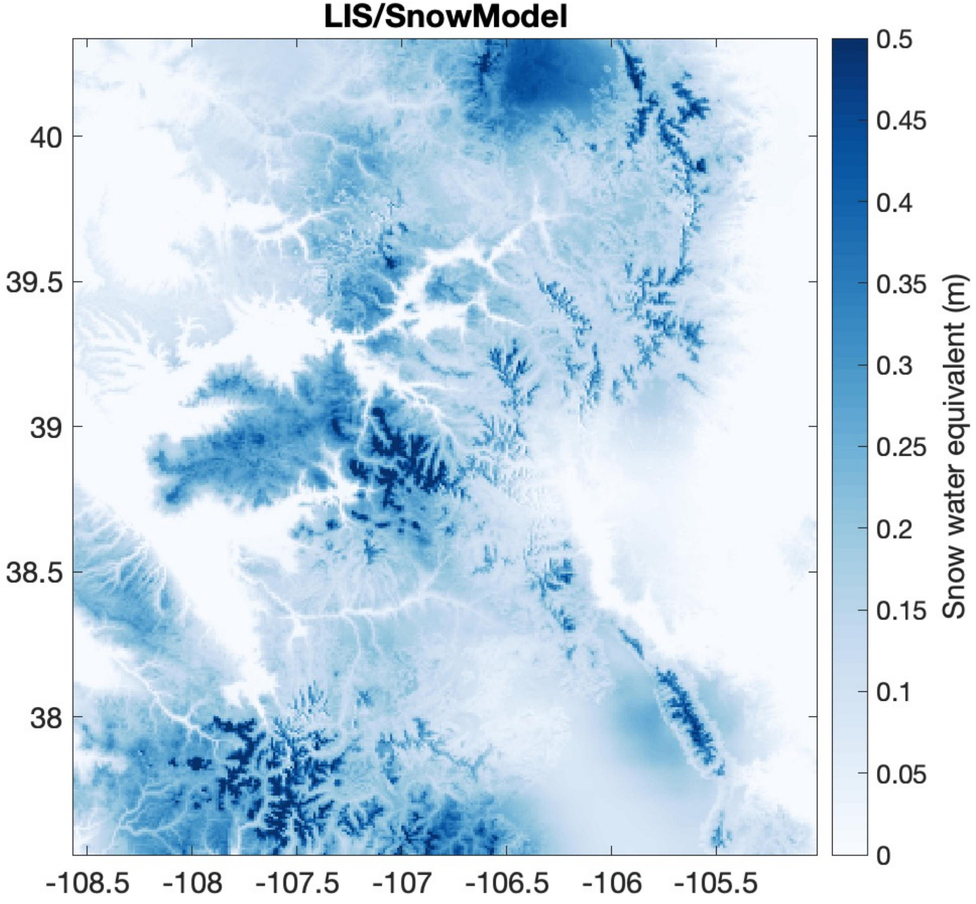


Noah-MP vs SnowModel comparison

Domain Topography







1 March 2017 SWE over western Colorado

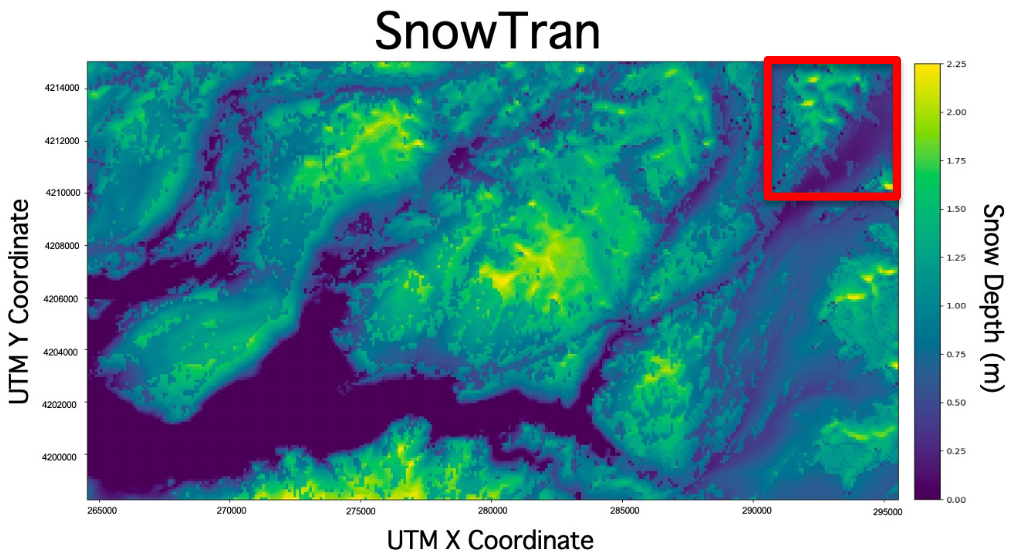
Both simulations approximately 1 km spatial resolution

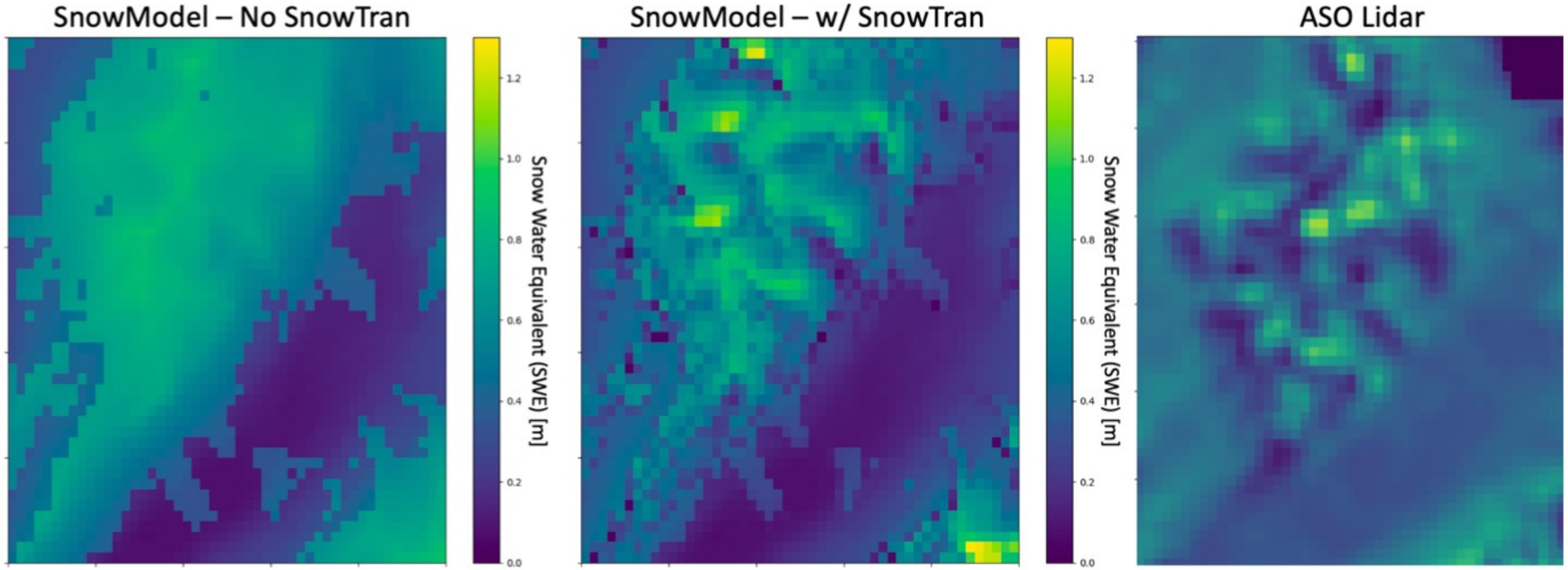
SnowModel has been aggregated from 100 m to 1 km for this comparison

SnowTran Snow Depth Comparison to Observations

Tuolumne River Basin

- LIS-SnowModel simulations
  100 m grid, NLDAS forcing
- With and without SnowTransport
- Comparison to ASO observations
- Largest differences likely due to meteorology

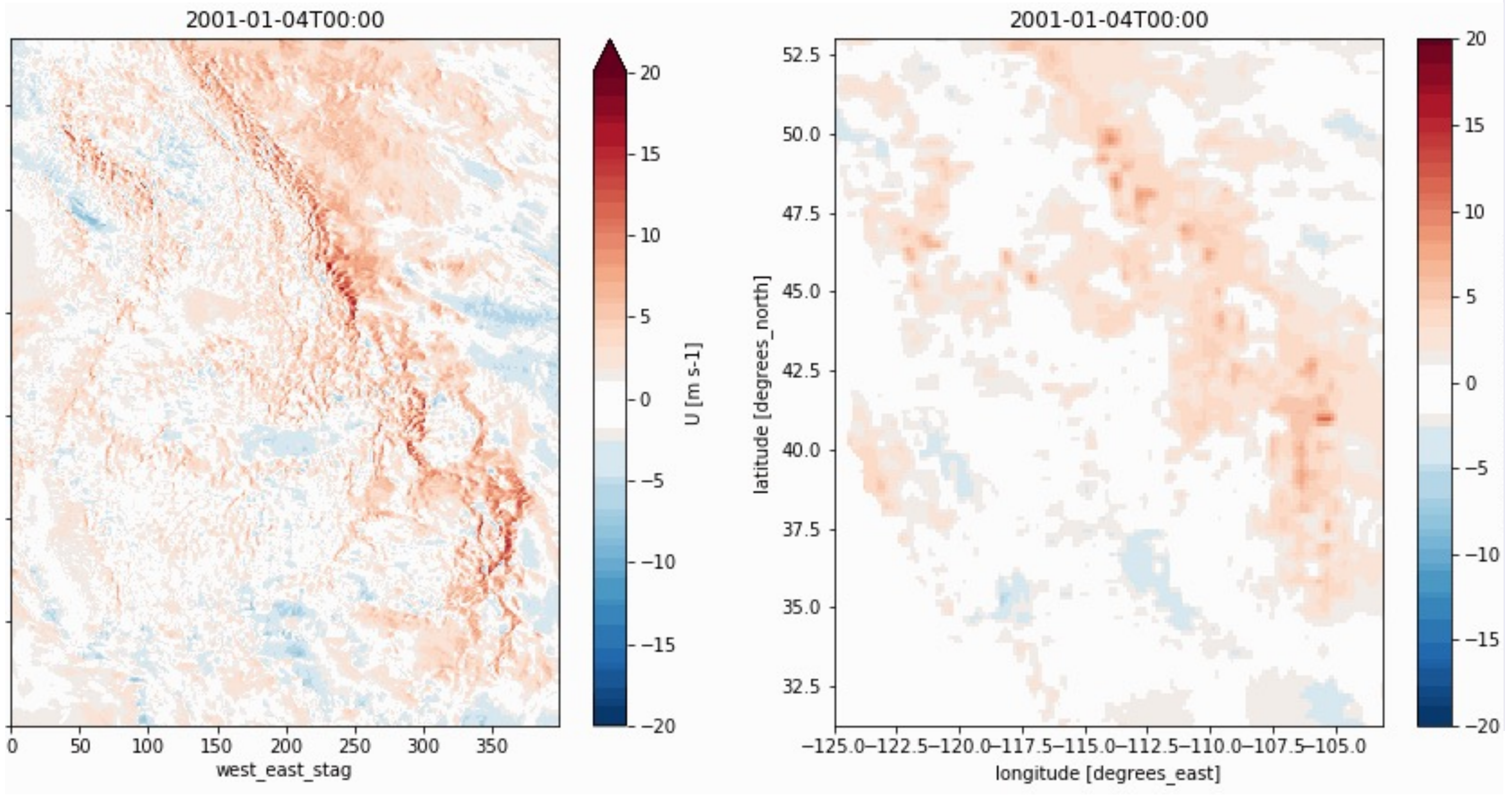


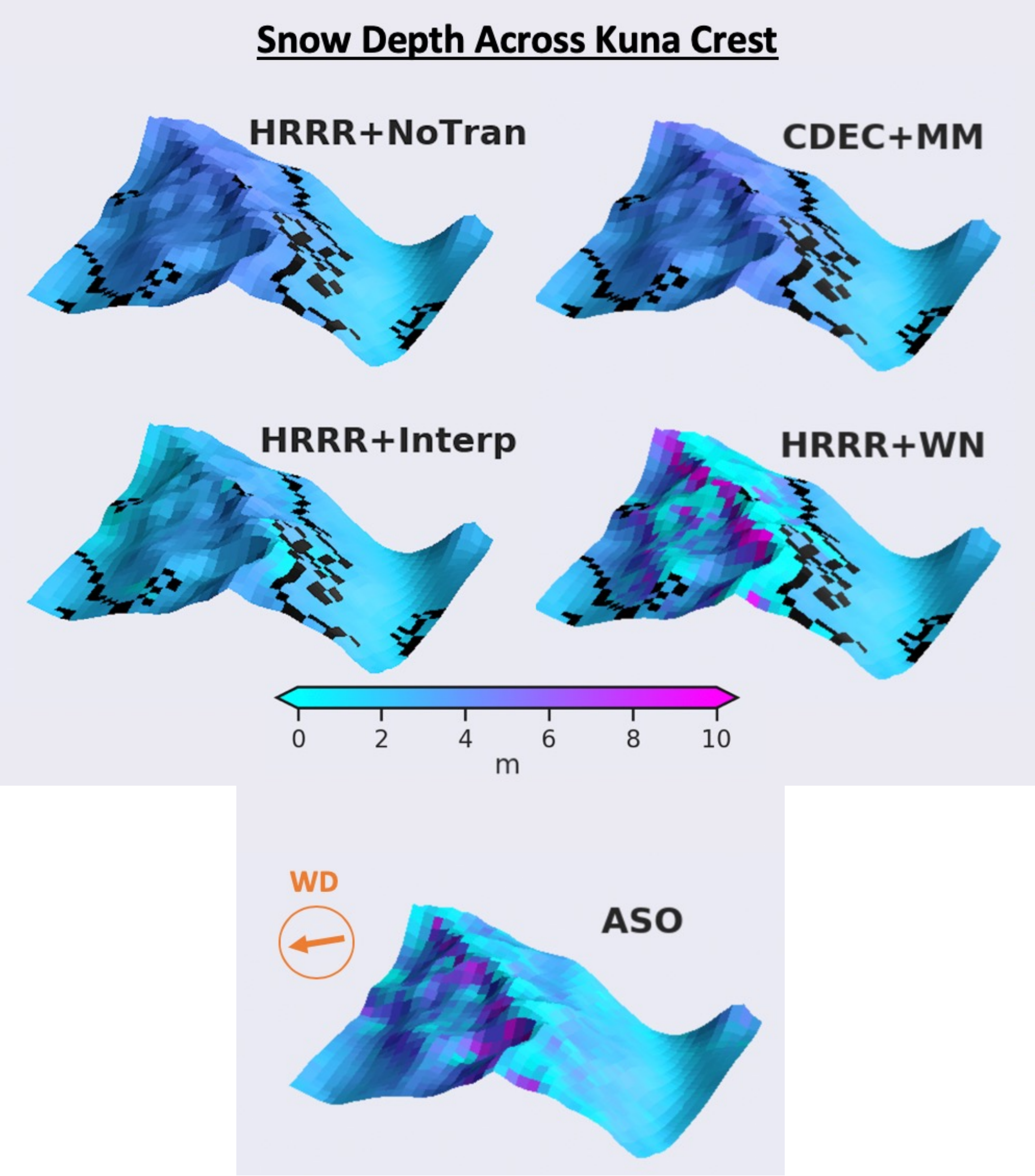


Importance of Meteorology

High-res WRF winds

NLDAS winds





Identifying wind improvements

- Large WRF database transferred to Discover
- LIS-reader developed to import WRF data
- Now testing for CONUS and Alaska (SnowEx 2022)

Reynolds et al 2020

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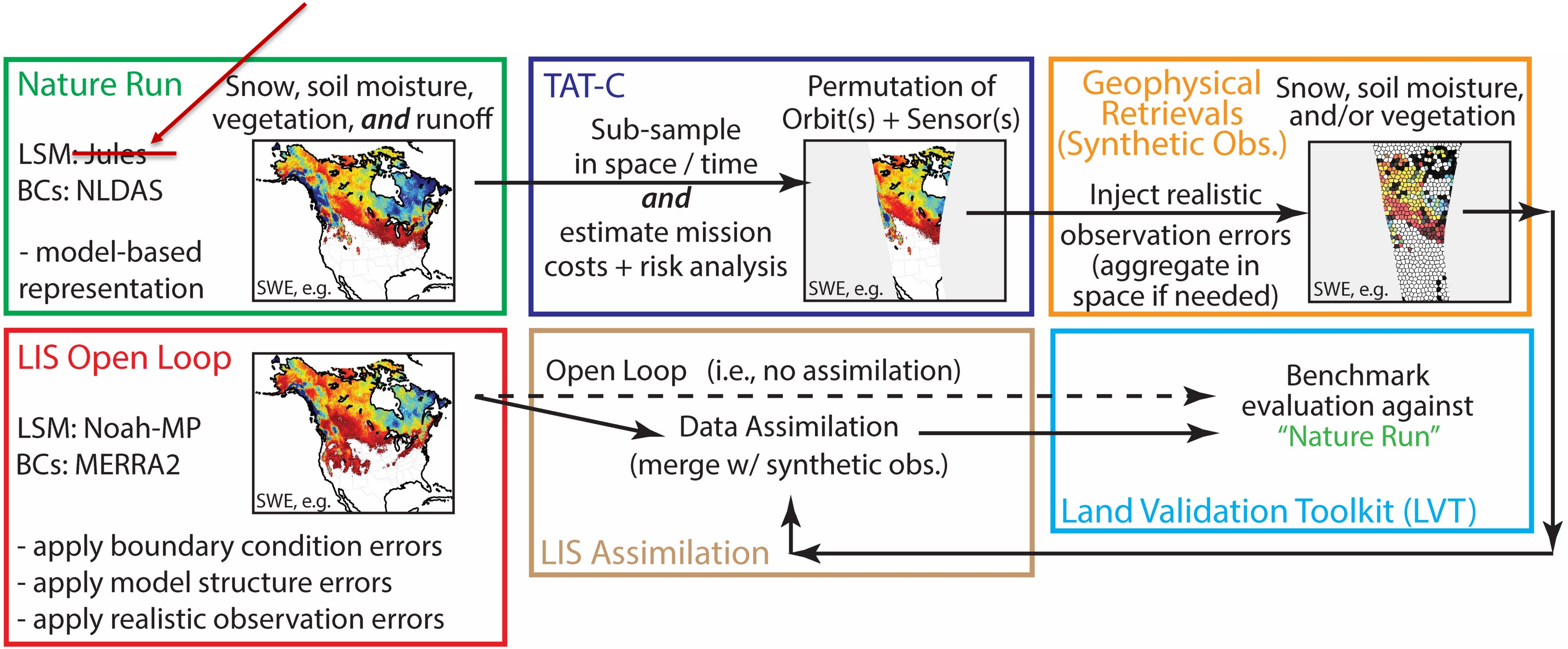
Technical Details

Bringing SnowModel into a continental scale OSSE

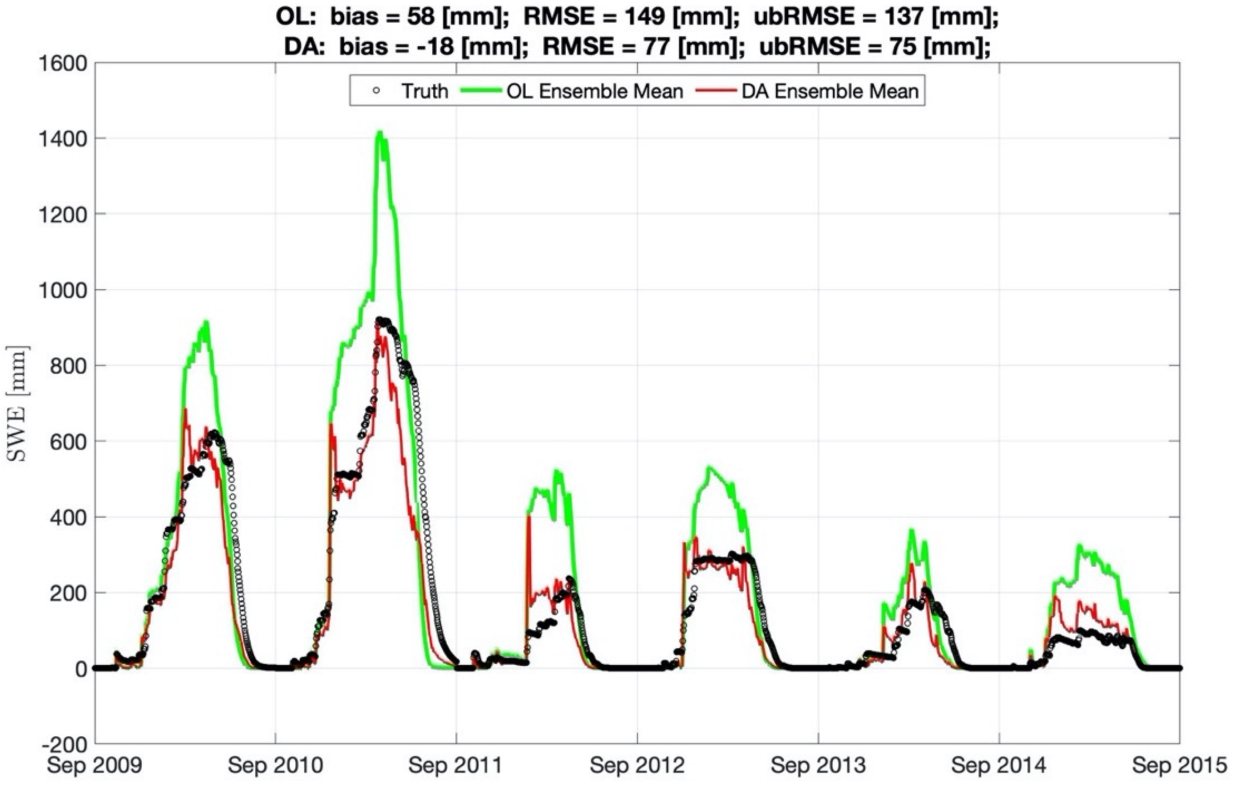


Innovation: ``**fraternal twin" experiment rather than "identical twin"** (AIST-16-0024)
Building on OSSE development with AIST-18-0041

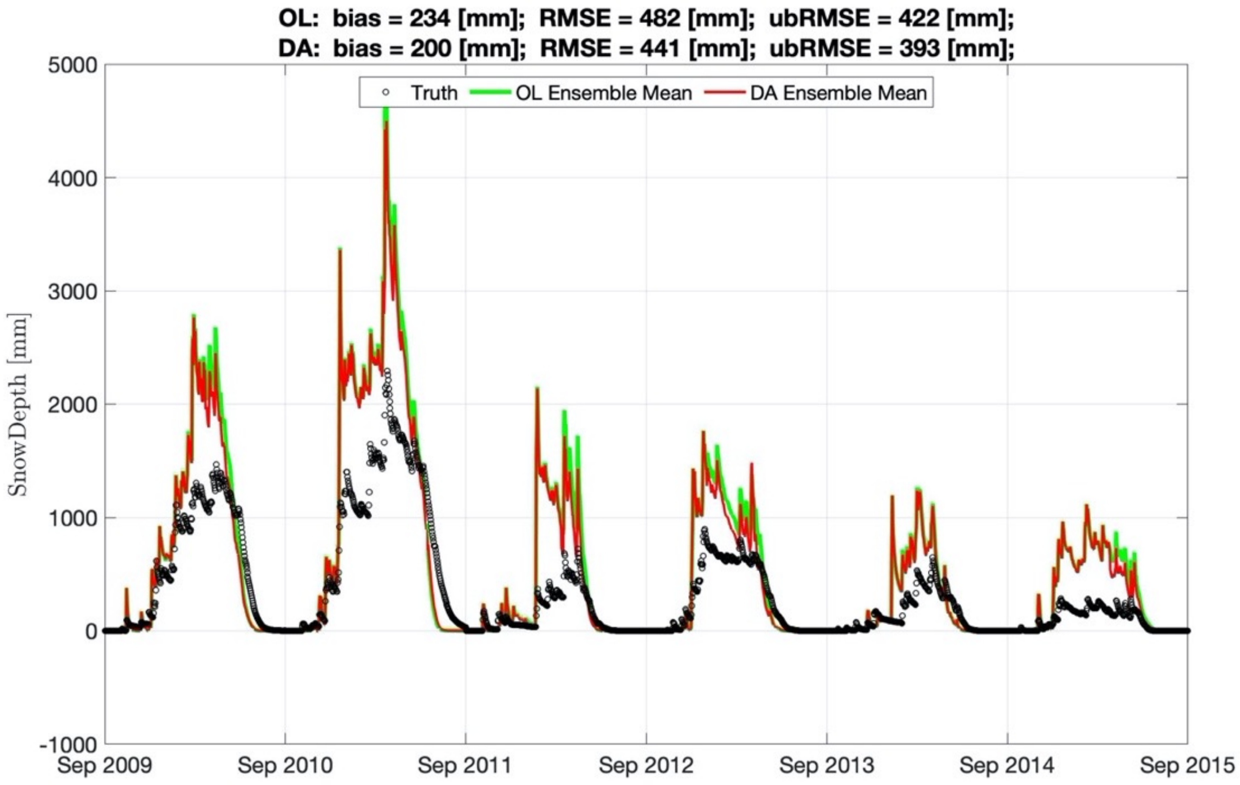
Initial OSSE simulation over Tuolumne

- Infinite swath lidar without clouds DA is extremely helpful
- Realistic swath and cloud masks decrease utility of direct DA dramatically

Wide swath, no clouds



Realistic swath, with clouds

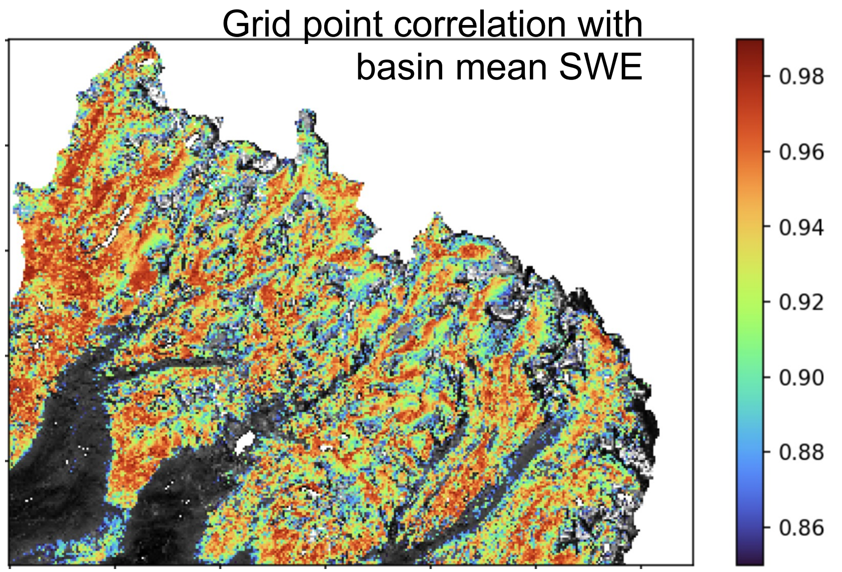


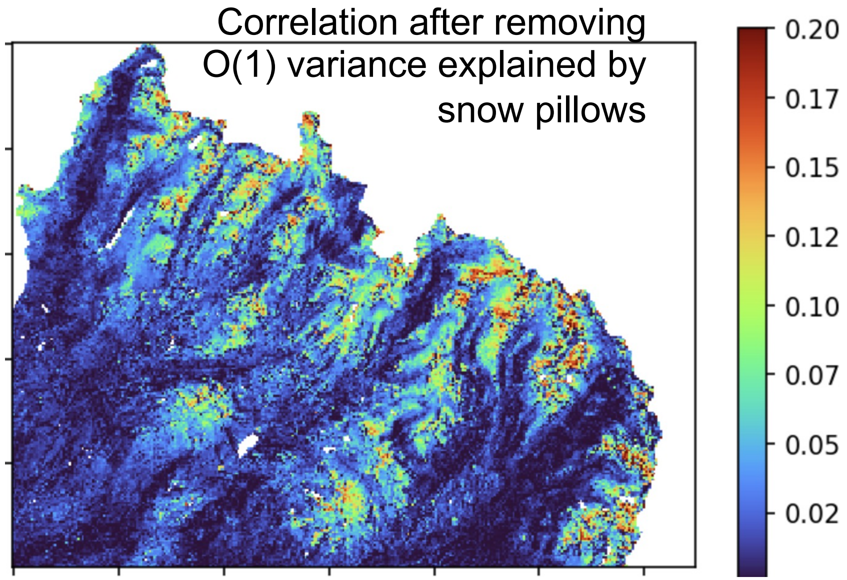
Exploiting Knowledge of Snow to Improve Model Data Fusion

- Limited spatial observations can be relevant to other locations (just not the exact value)
- Spatial autocorrelation is weak
- Point to point temporal correlation is strong
  - $r^2 > 0.95$
- Based on existing measurement network, greatest remaining uncertainty (in Tuolumne) is above tree line

A good model combined with prior measurements can provide the spatial covariance matrix necessary to ingest sparse or preferential sampling from lidar, SAR, signals of opportunity, stereo optical, …combinations?

ASO Temporal Correlations



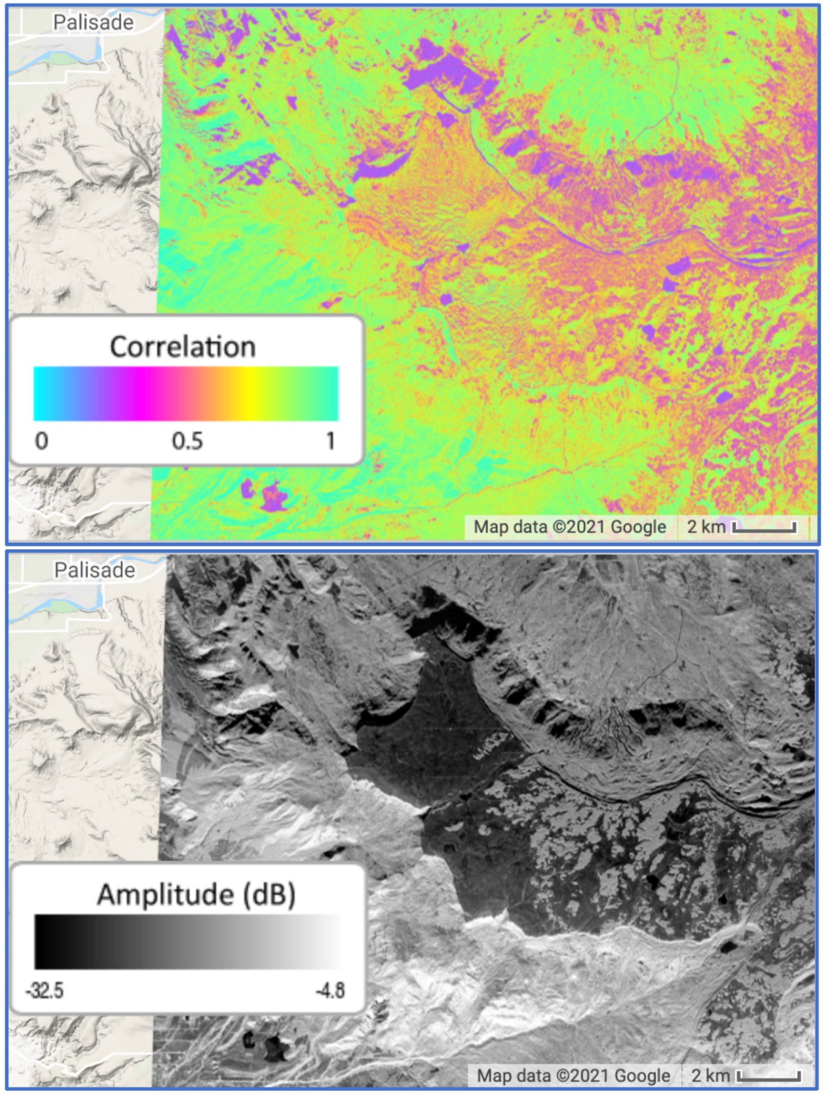


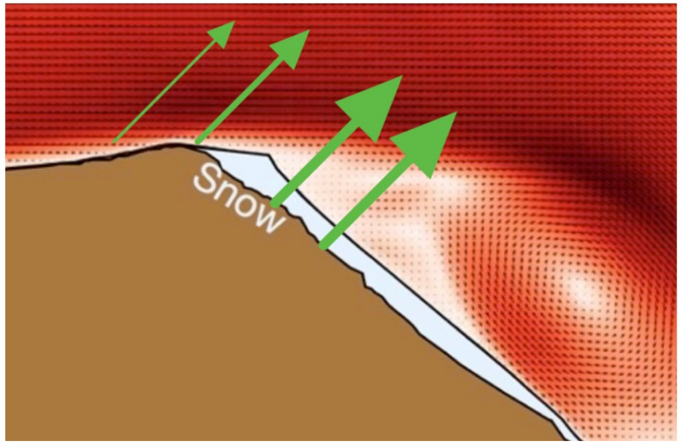
Preferential sampling challenges

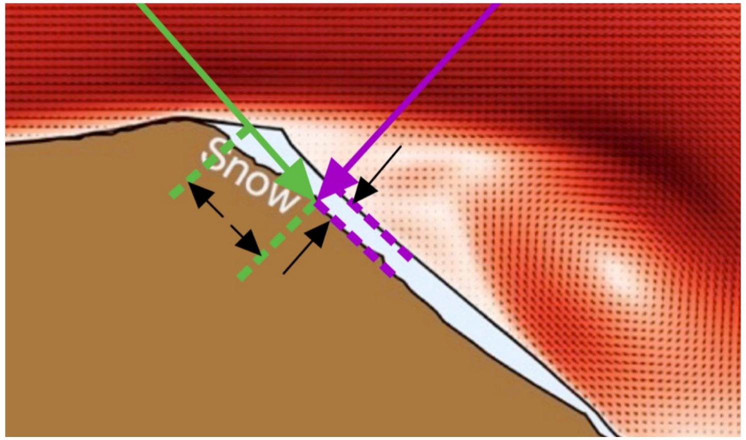
- All sampling has some degree of preferentiality
- Spatial heterogeneity convolved with sampling limits can be mis-leading

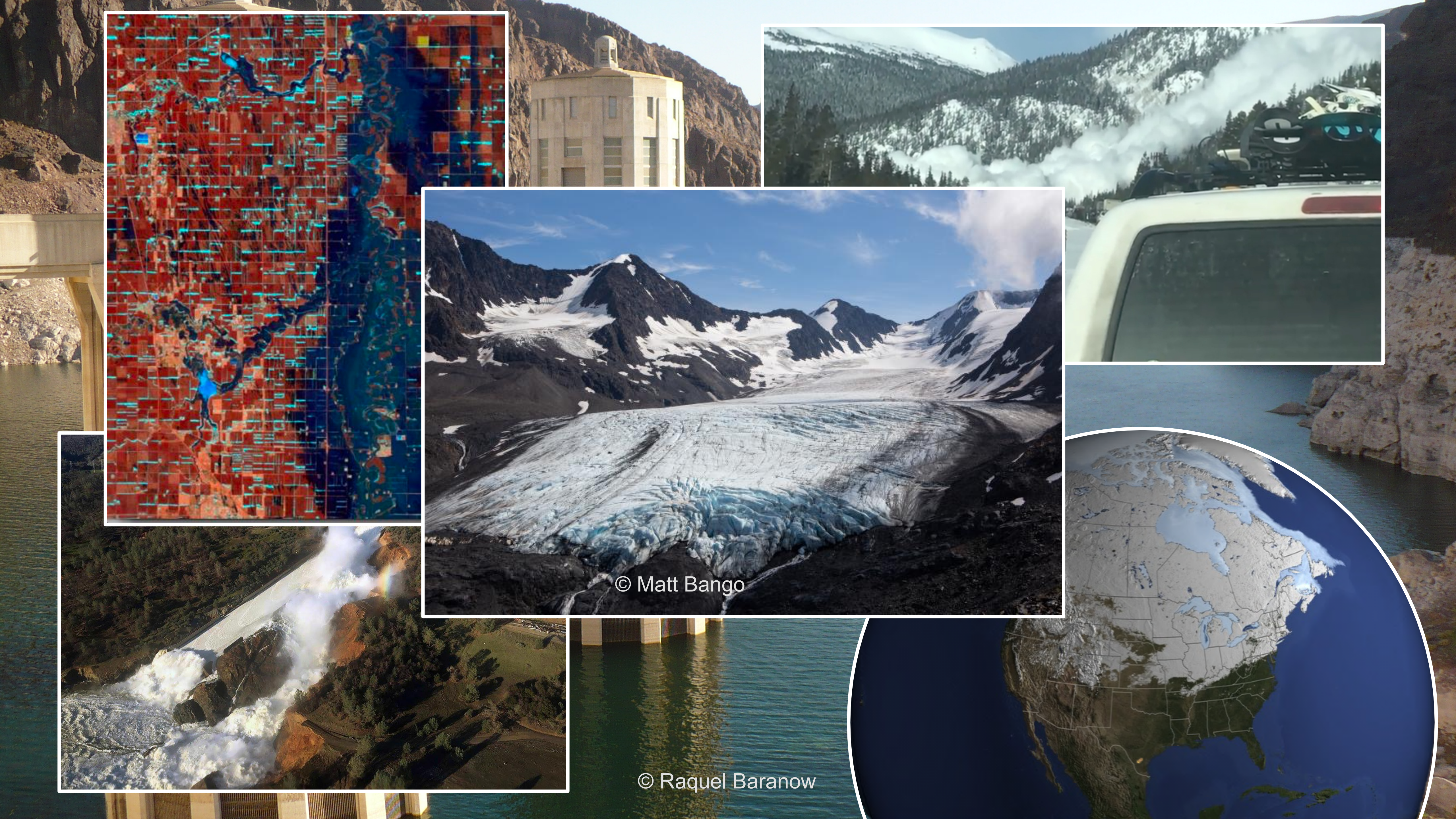
- Coherence & amplitude covary with snow depth
- Signal SWE path length varies with look angle

InSAR pair correlation and amplitude





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Summary

- Snow is complicated, better modeling doesn't have to be
- SnowModel runs in LIS
  - (parallel scaling is improving)
- LIS-SnowModel has been used in a regional OSSE
- Spatial heterogeneity and preferential sampling create new challenges
- LIS-SnowModel provides a strong foundation for future model-data fusion activities in SnowEx and beyond